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TITLE

WUSCHEL (WUS) GENE HOMOLOGS

This application claims the benefit of U.S. Provisional Application No. 60/157216, filed October 1, 1999.

FIELD OF THE INVENTION

This invention is in the field of plant molecular biology. More specifically, this invention pertains to nucleic acid fragments encoding Wuschel (WUS) proteins in plants and seeds.

BACKGROUND OF THE INVENTION

Organ formation in plants occurs via the activity of apical meristems. Plant meristems contain a pool of stem cells, which are able to self-maintain, give rise to a variety of cell types including cells required for organ initiation. The initiation and maintenance of stem cells and their integration into organ-forming meristems are thus the basis for continuous plant development.

The Wuschel protein, designated hereafter as WUS, plays a key role in the initiation and maintenance of the apical meristem, which contains a pool of pluripotent stem cells (Endrizzi et al., 1996, *Plant Journal* 10:967-979; Laux et al., 1996 *Development* 122:87-96; and Mayer et al., 1998 *Cell* 95:805-815). Arabidopsis plants mutant for the WUS gene contain stem cells that are misspecified and that appear to undergo differentiation. WUS encodes a novel homeodomain protein which presumably functions as a transcriptional regulator (Mayer et al., 1998 *Cell* 95:805-815). The stem cell population of Arabidopsis shoot meristems is believed to be maintained by a regulatory loop between the CLAVATA (CLV) genes which promote organ initiation and the WUS gene which is required for stem cell identity, with the CLV genes repressing WUS at the transcript level, and WUS expression being sufficient to induce meristem cell identity and the expression of the stem cell marker CLV3 (Brand et al. (2000) *Science* 289:617-619; Schoof et al. (2000) *Cell* 100:635-644). Constitutive expression of WUS in Arabidopsis has been recently shown to lead to adventitious shoot proliferation from leaves (*in planta*) (Laux, T., Talk Presented at the XVI International Botanical Congress Meeting, August 1-7, 1999, St. Louis, MO).

There is a great deal of interest in identifying the genes that encode proteins involved in development in plants, generally toward the objective of altering plant growth and architecture. WUS represents one such gene. However, the WUS gene can also be used for the novel application of stimulating *in vitro* growth of plant tissue and improving transformation. In this manner, this gene can expand the range of tissues types targeted for transformation. Specifically, the WUS gene may be used to improve meristem transformation frequencies and could result in genotype independent transformation of many important crops such as maize, soybean and sunflower. Furthermore, transformation into meristems would stimulate the formation of new apical initials reducing the chimeric nature

of the transgenic events. Lastly, ectopic expression into non-meristematic cells would stimulate adventive meristem formation. This could lead to transformation of non-traditional tissues such as leaves, leaf bases, stem tissue, etc. Alternatively, transformation of a more traditional target such as callus or the scutellum of immature embryos could promote a “non-traditional” growth response, i.e. meristems in place of somatic embryos. In addition, WUS may also be used as a genetic marker for meristems. Accordingly, the availability of nucleic acid sequences encoding all or a portion of a WUS protein would facilitate studies to better understand programmed development in plants, provide genetic tools to enhance the efficiency of gene transfer into meristem tissue and help provide alternative transformation methods in several important crops.

SUMMARY OF THE INVENTION

The present invention concerns an isolated polynucleotide comprising a nucleotide sequence selected from the group consisting of: (a) a first nucleotide sequence encoding a polypeptide of at least 50 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:2, 4, and 12, (b) a second nucleotide sequence encoding a polypeptide of at least 100 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:14, 16, 18, and 20, (c) a third nucleotide sequence encoding a polypeptide of at least 180 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:24, (d) a fourth nucleotide sequence encoding a polypeptide of at least 230 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:22, (e) a fifth nucleotide sequence encoding a polypeptide of at least 100 amino acids having at least 80% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:6, 8, and 10, and (f) a sixth nucleotide sequence comprising the complement of (a), (b), (c), (d), or (e).

In a second embodiment, it is preferred that the isolated polynucleotide of the claimed invention comprises a first nucleotide sequence which comprises a nucleic acid sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23 that codes for the polypeptide selected from the group consisting of SEQ ID NOs:2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24.

In a third embodiment, this invention concerns an isolated polynucleotide comprising a nucleotide sequence of at least one of 60 (preferably at least one of 40, most preferably at least one of 30) contiguous nucleotides derived from a nucleotide sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23 and the complement of such nucleotide sequences.

In a fourth embodiment, this invention relates to a chimeric gene comprising an isolated polynucleotide of the present invention operably linked to at least one suitable regulatory sequence.

In a fifth embodiment, the present invention concerns an isolated host cell comprising a chimeric gene of the present invention or an isolated polynucleotide of the present invention. The host cell may be eukaryotic, such as a yeast or a plant cell, or prokaryotic, such as a bacterial cell. The present invention also relates to a virus, preferably a baculovirus, comprising an isolated polynucleotide of the present invention or a chimeric gene of the present invention.

In a sixth embodiment, the invention also relates to a process for producing an isolated host cell comprising a chimeric gene of the present invention or an isolated polynucleotide of the present invention, the process comprising either transforming or transfecting an isolated compatible host cell with a chimeric gene or isolated polynucleotide of the present invention.

In a seventh embodiment, the invention concerns an isolated WUS polypeptide selected from the group consisting of: (a) a polypeptide of at least 50 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:2, 4, and 12, (b) a polypeptide of at least 100 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:14, 16, 18, and 20, (c) a polypeptide of at least 180 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:24, (d) a polypeptide of at least 230 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:22, and (e) a polypeptide of at least 100 amino acids having at least 80% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:6, 8, and 10.

In an eighth embodiment, the invention relates to a method of selecting an isolated polynucleotide that affects the level of expression of a WUS polypeptide or enzyme activity in a host cell, preferably a plant cell, the method comprising the steps of: (a) constructing an isolated polynucleotide of the present invention or an isolated chimeric gene of the present invention; (b) introducing the isolated polynucleotide or the isolated chimeric gene into a host cell; (c) measuring the level of the WUS polypeptide or enzyme activity in the host cell containing the isolated polynucleotide; and (d) comparing the level of the WUS polypeptide or enzyme activity in the host cell containing the isolated polynucleotide with the level of the WUS polypeptide or enzyme activity in the host cell that does not contain the isolated polynucleotide.

In a ninth embodiment, the invention concerns a method of obtaining a nucleic acid fragment encoding a substantial portion of a WUS polypeptide, preferably a plant WUS polypeptide, comprising the steps of: synthesizing an oligonucleotide primer comprising a nucleotide sequence of at least one of 60 (preferably at least one of 40, most preferably at least one of 30) contiguous nucleotides derived from a nucleotide sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23, and the complement of such nucleotide sequences; and amplifying a nucleic acid fragment (preferably a cDNA inserted in a cloning vector) using the oligonucleotide primer. The amplified nucleic acid fragment preferably will encode a substantial portion of a WUS amino acid sequence.

In a tenth embodiment, this invention relates to a method of obtaining a nucleic acid fragment encoding all or a substantial portion of the amino acid sequence encoding a WUS polypeptide comprising the steps of: probing a cDNA or genomic library with an isolated polynucleotide of the present invention; identifying a DNA clone that hybridizes with an isolated polynucleotide of the present invention; isolating the identified DNA clone; and sequencing the cDNA or genomic fragment that comprises the isolated DNA clone.

In an eleventh embodiment, this invention concerns a composition, such as a hybridization mixture, comprising an isolated polynucleotide of the present invention.

In a twelfth embodiment, this invention concerns a method for positive selection of a transformed cell comprising: (a) transforming a host cell with the chimeric gene of the present invention or an expression cassette of the present invention; and (b) growing the transformed host cell, preferably a plant cell, such as a monocot or a dicot, under conditions which allow expression of the WUS polynucleotide in an amount sufficient to complement a null mutant to provide a positive selection means.

In a thirteenth embodiment, this invention relates to a method of altering the level of expression of a WUS protein in a host cell comprising: (a) transforming a host cell with a chimeric gene of the present invention; and (b) growing the transformed host cell under conditions that are suitable for expression of the chimeric gene wherein expression of the chimeric gene results in production of altered levels of the WUS protein in the transformed host cell.

BRIEF DESCRIPTION OF THE DRAWING AND SEQUENCE LISTINGS

The invention can be more fully understood from the following detailed description and the accompanying drawing and Sequence Listing which form a part of this application.

Figure 1 shows an alignment of the amino acid sequences of WUS protein encoded by the nucleotide sequences derived from corn clone cpi1c.pk012.p19 (SEQ ID NO:4), corn clone p0058.chpab57r (SEQ ID NO:10), soybean clone ses4d.pk0033.c8 (SEQ ID NO:20), soybean clone sgs5c.pk0002.f2 (SEQ ID NO:22), and a contig assembled using soybean

clone ssm.pk0060.h4 and NCBI GenBank Identifier (GI) No. 4395781 (SEQ ID NO:24), and the WUS protein from *Arabidopsis thaliana* (NCBI GI No. 4090200; SEQ ID NO:25).

Amino acids which are conserved among all and at least two sequences with an amino acid at that position are indicated with an asterisk (*). Dashes are used by the program to maximize alignment of the sequences.

Table 1 lists the polypeptides that are described herein, the designation of the cDNA clones that comprise the nucleic acid fragments encoding polypeptides representing all or a substantial portion of these polypeptides, and the corresponding identifier (SEQ ID NO:) as used in the attached Sequence Listing. Table 1 also identifies the cDNA clones as individual ESTs ("EST"), the sequences of the entire cDNA inserts comprising the indicated cDNA clones ("FIS"), contigs assembled from two or more ESTs ("Contig"), contigs assembled from an FIS and one or more ESTs or PCR fragment sequence ("Contig*"), or sequences encoding the entire protein derived from an EST, an FIS, a contig, or an FIS and PCR fragment sequence ("CGS"). Nucleotide SEQ ID NOs:1, 5, 11, and 15 correspond to nucleotide SEQ ID NOs:1, 3, 5, and 7, respectively, presented in U.S. Provisional Application No. 60/157216, filed October 1, 1999. Amino acid SEQ ID NOs:2, 6, 12, and 16 correspond to amino acid SEQ ID NOs:2, 4, 6, and 8, respectively, presented in U.S. Provisional Application No. 60/157216, filed October 1, 1999. The sequence descriptions and Sequence Listing attached hereto comply with the rules governing nucleotide and/or amino acid sequence disclosures in patent applications as set forth in 37 C.F.R. §1.821-1.825.

TABLE 1
WUS Proteins

Protein (Plant Source)	Clone Designation	Status	SEQ ID NO:	
			(Nucleotide)	(Amino Acid)
WUS Protein (Corn)	Contig of cpg1c.pk006.b16 cpi1c.pk012.p19	Contig	1	2
WUS Protein (Corn)	cpi1c.pk012.p19 (FIS)	CGS	3	4
WUS Protein (Corn)	p0016.ctsas50r	EST	5	6
WUS Protein (Corn)	p0016.ctsas50r	FIS	7	8
WUS Protein (Corn)	p0058.chpab57r (FIS)	CGS	9	10
WUS Protein (Corn)	p0083.cldev71r	EST	11	12
WUS Protein (Corn)	p0083.cldev71r	FIS	13	14
WUS Protein (Soybean)	Contig of scr1c.pk001.d2 ses4d.pk0033.c8	Contig	15	16
WUS Protein (Soybean)	scr1c.pk001.d2	FIS	17	18

WUS Protein (Soybean)	ses4d.pk0033.c8 (FIS)	CGS	19	20
WUS Protein (Soybean)	sgs5c.pk0002.f2 (EST)	CGS	21	22
WUS Protein (Soybean)	Contig of ssm.pk0060.h4 (FIS)	CGS	23	24
NCBI GI No. 4395781				

The Sequence Listing contains the one letter code for nucleotide sequence characters and the three letter codes for amino acids as defined in conformity with the IUPAC-IUBMB standards described in *Nucleic Acids Res.* 13:3021-3030 (1985) and in the *Biochemical J.* 219 (No. 2):345-373 (1984) which are herein incorporated by reference. The symbols and format used for nucleotide and amino acid sequence data comply with the rules set forth in 37 C.F.R. §1.822.

DETAILED DESCRIPTION OF THE INVENTION

In the context of this disclosure, a number of terms shall be utilized. The terms “polynucleotide”, “polynucleotide sequence”, “nucleic acid sequence”, and “nucleic acid fragment”/“isolated nucleic acid fragment” are used interchangeably herein. These terms encompass nucleotide sequences and the like. A polynucleotide may be a polymer of RNA or DNA that is single- or double-stranded, that optionally contains synthetic, non-natural or altered nucleotide bases. A polynucleotide in the form of a polymer of DNA may be comprised of one or more segments of cDNA, genomic DNA, synthetic DNA, or mixtures thereof. An isolated polynucleotide of the present invention may include at least one of 60 contiguous nucleotides, preferably at least one of 40 contiguous nucleotides, most preferably one of at least 30 contiguous nucleotides derived from SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, or 23, or the complement of such sequences.

The term “isolated” polynucleotide refers to a polynucleotide that is substantially free from other nucleic acid sequences, such as other chromosomal and extrachromosomal DNA and RNA, that normally accompany or interact with it as found in its naturally occurring environment. Isolated polynucleotides may be purified from a host cell in which they naturally occur. Conventional nucleic acid purification methods known to skilled artisans may be used to obtain isolated polynucleotides. The term also embraces recombinant polynucleotides and chemically synthesized polynucleotides.

The term “recombinant” means, for example, that a nucleic acid sequence is made by an artificial combination of two otherwise separated segments of sequence, e.g., by chemical synthesis or by the manipulation of isolated nucleic acids by genetic engineering techniques.

As used herein, “contig” refers to a nucleotide sequence that is assembled from two or more constituent nucleotide sequences that share common or overlapping regions of sequence homology. For example, the nucleotide sequences of two or more nucleic acid fragments can be compared and aligned in order to identify common or overlapping

sequences. Where common or overlapping sequences exist between two or more nucleic acid fragments, the sequences (and thus their corresponding nucleic acid fragments) can be assembled into a single contiguous nucleotide sequence.

As used herein, "substantially similar" refers to nucleic acid fragments wherein changes in one or more nucleotide bases results in substitution of one or more amino acids, but do not affect the functional properties of the polypeptide encoded by the nucleotide sequence. "Substantially similar" also refers to nucleic acid fragments wherein changes in one or more nucleotide bases does not affect the ability of the nucleic acid fragment to mediate alteration of gene expression by gene silencing through for example antisense or co-suppression technology. "Substantially similar" also refers to modifications of the nucleic acid fragments of the instant invention such as deletion or insertion of one or more nucleotides that do not substantially affect the functional properties of the resulting transcript vis-à-vis the ability to mediate gene silencing or alteration of the functional properties of the resulting protein molecule. It is therefore understood that the invention encompasses more than the specific exemplary nucleotide or amino acid sequences and includes functional equivalents thereof. The terms "substantially similar" and "corresponding substantially" are used interchangeably herein.

Substantially similar nucleic acid fragments may be selected by screening nucleic acid fragments representing subfragments or modifications of the nucleic acid fragments of the instant invention, wherein one or more nucleotides are substituted, deleted and/or inserted, for their ability to affect the level of the polypeptide encoded by the unmodified nucleic acid fragment in a plant or plant cell. For example, a substantially similar nucleic acid fragment representing at least one of 30 contiguous nucleotides derived from the instant nucleic acid fragment can be constructed and introduced into a plant or plant cell. The level of the polypeptide encoded by the unmodified nucleic acid fragment present in a plant or plant cell exposed to the substantially similar nucleic fragment can then be compared to the level of the polypeptide in a plant or plant cell that is not exposed to the substantially similar nucleic acid fragment.

For example, it is well known in the art that antisense suppression and co-suppression of gene expression may be accomplished using nucleic acid fragments representing less than the entire coding region of a gene, and by using nucleic acid fragments that do not share 100% sequence identity with the gene to be suppressed. Moreover, alterations in a nucleic acid fragment which result in the production of a chemically equivalent amino acid at a given site, but do not effect the functional properties of the encoded polypeptide, are well known in the art. Thus, a codon for the amino acid alanine, a hydrophobic amino acid, may be substituted by a codon encoding another less hydrophobic residue, such as glycine, or a more hydrophobic residue, such as valine, leucine, or isoleucine. Similarly, changes which result in substitution of one negatively charged residue for another, such as aspartic acid for

glutamic acid, or one positively charged residue for another, such as lysine for arginine, can also be expected to produce a functionally equivalent product. Nucleotide changes which result in alteration of the N-terminal and C-terminal portions of the polypeptide molecule would also not be expected to alter the activity of the polypeptide. Each of the proposed
5 modifications is well within the routine skill in the art, as is determination of retention of biological activity of the encoded products. Consequently, an isolated polynucleotide comprising a nucleotide sequence of at least one of 60 (preferably at least one of 40, most preferably at least one of 30) contiguous nucleotides derived from a nucleotide sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and
10 23, and the complement of such nucleotide sequences may be used in methods of selecting an isolated polynucleotide that affects the expression of a WUS polypeptide in a host cell. A method of selecting an isolated polynucleotide that affects the level of expression of a polypeptide in a virus or in a host cell (eukaryotic, such as plant or yeast, prokaryotic such as bacterial) may comprise the steps of: constructing an isolated polynucleotide of the present
15 invention or an isolated chimeric gene of the present invention; introducing the isolated polynucleotide or the isolated chimeric gene into a host cell; measuring the level of a polypeptide or enzyme activity in the host cell containing the isolated polynucleotide; and comparing the level of a polypeptide or enzyme activity in the host cell containing the isolated polynucleotide with the level of a polypeptide or enzyme activity in a host cell that
20 does not contain the isolated polynucleotide.

Moreover, substantially similar nucleic acid fragments may also be characterized by their ability to hybridize. Estimates of such homology are provided by either DNA-DNA or DNA-RNA hybridization under conditions of stringency as is well understood by those skilled in the art (Hames and Higgins, Eds. (1985) *Nucleic Acid Hybridisation*, IRL Press,
25 Oxford, U.K.). Stringency conditions can be adjusted to screen for moderately similar fragments, such as homologous sequences from distantly related organisms, to highly similar fragments, such as genes that duplicate functional enzymes from closely related organisms. Post-hybridization washes determine stringency conditions. One set of preferred conditions uses a series of washes starting with 6X SSC, 0.5% SDS at room temperature for 15 min,
30 then repeated with 2X SSC, 0.5% SDS at 45°C for 30 min, and then repeated twice with 0.2X SSC, 0.5% SDS at 50°C for 30 min. A more preferred set of stringent conditions uses higher temperatures in which the washes are identical to those above except for the temperature of the final two 30 min washes in 0.2X SSC, 0.5% SDS was increased to 60°C. Another preferred set of highly stringent conditions uses two final washes in 0.1X SSC,
35 0.1% SDS at 65°C.

Substantially similar nucleic acid fragments of the instant invention may also be characterized by the percent identity of the amino acid sequences that they encode to the amino acid sequences disclosed herein, as determined by algorithms commonly employed by

those skilled in this art. Suitable nucleic acid fragments (isolated polynucleotides of the present invention) encode polypeptides that are at least about 70% identical, preferably at least about 80% identical to the amino acid sequences reported herein. Preferred nucleic acid fragments encode amino acid sequences that are about 85% identical to the amino acid sequences reported herein. More preferred nucleic acid fragments encode amino acid sequences that are at least about 90% identical to the amino acid sequences reported herein. Most preferred are nucleic acid fragments that encode amino acid sequences that are at least about 95% identical to the amino acid sequences reported herein. Suitable nucleic acid fragments not only have the above identities but typically encode a polypeptide having at least 50 amino acids, preferably at least 100 amino acids, more preferably at least 150 or 180 amino acids, still more preferably at least 200 or 230 amino acids, and most preferably at least 250 amino acids. Sequence alignments and percent identity calculations were performed using the Megalign program of the LASERGENE bioinformatics computing suite (DNASTAR Inc., Madison, WI). Multiple alignment of the sequences was performed using the Clustal method of alignment (Higgins and Sharp (1989) *CABIOS*. 5:151-153) with the default parameters (GAP PENALTY=10, GAP LENGTH PENALTY=10). Default parameters for pairwise alignments using the Clustal method were KTUPLE 1, GAP PENALTY=3, WINDOW=5 and DIAGONALS SAVED=5.

A "substantial portion" of an amino acid or nucleotide sequence comprises an amino acid or a nucleotide sequence that is sufficient to afford putative identification of the protein or gene that the amino acid or nucleotide sequence comprises. Amino acid and nucleotide sequences can be evaluated either manually by one skilled in the art, or by using computer-based sequence comparison and identification tools that employ algorithms such as BLAST (Basic Local Alignment Search Tool; Altschul et al. (1993) *J. Mol. Biol.* 215:403-410; see also www.ncbi.nlm.nih.gov/BLAST/). In general, a sequence of ten or more contiguous amino acids or thirty or more contiguous nucleotides is necessary in order to putatively identify a polypeptide or nucleic acid sequence as homologous to a known protein or gene. Moreover, with respect to nucleotide sequences, gene-specific oligonucleotide probes comprising 30 or more contiguous nucleotides may be used in sequence-dependent methods of gene identification (e.g., Southern hybridization) and isolation (e.g., *in situ* hybridization of bacterial colonies or bacteriophage plaques). In addition, short oligonucleotides of 12 or more nucleotides may be used as amplification primers in PCR in order to obtain a particular nucleic acid fragment comprising the primers. Accordingly, a "substantial portion" of a nucleotide sequence comprises a nucleotide sequence that will afford specific identification and/or isolation of a nucleic acid fragment comprising the sequence. The instant specification teaches amino acid and nucleotide sequences encoding polypeptides that comprise one or more particular plant proteins. The skilled artisan, having the benefit of the sequences as reported herein, may now use all or a substantial portion of the disclosed

sequences for purposes known to those skilled in this art. Accordingly, the instant invention comprises the complete sequences as reported in the accompanying Sequence Listing, as well as substantial portions of those sequences as defined above.

“Codon degeneracy” refers to divergence in the genetic code permitting variation of the nucleotide sequence without effecting the amino acid sequence of an encoded polypeptide. Accordingly, the instant invention relates to any nucleic acid fragment comprising a nucleotide sequence that encodes all or a substantial portion of the amino acid sequences set forth herein. The skilled artisan is well aware of the “codon-bias” exhibited by a specific host cell in usage of nucleotide codons to specify a given amino acid.

Therefore, when synthesizing a nucleic acid fragment for improved expression in a host cell, it is desirable to design the nucleic acid fragment such that its frequency of codon usage approaches the frequency of preferred codon usage of the host cell.

“Synthetic nucleic acid fragments” can be assembled from oligonucleotide building blocks that are chemically synthesized using procedures known to those skilled in the art.

These building blocks are ligated and annealed to form larger nucleic acid fragments which may then be enzymatically assembled to construct the entire desired nucleic acid fragment. “Chemically synthesized”, as related to a nucleic acid fragment, means that the component nucleotides were assembled *in vitro*. Manual chemical synthesis of nucleic acid fragments may be accomplished using well established procedures, or automated chemical synthesis can be performed using one of a number of commercially available machines. Accordingly, the nucleic acid fragments can be tailored for optimal gene expression based on optimization of the nucleotide sequence to reflect the codon bias of the host cell. The skilled artisan appreciates the likelihood of successful gene expression if codon usage is biased towards those codons favored by the host. Determination of preferred codons can be based on a survey of genes derived from the host cell where sequence information is available.

“Gene” refers to a nucleic acid fragment that expresses a specific protein, including regulatory sequences preceding (5' non-coding sequences) and following (3' non-coding sequences) the coding sequence. “Native gene” refers to a gene as found in nature with its own regulatory sequences. “Chimeric gene” refers any gene that is not a native gene, comprising regulatory and coding sequences that are not found together in nature.

Accordingly, a chimeric gene may comprise regulatory sequences and coding sequences that are derived from different sources, or regulatory sequences and coding sequences derived from the same source, but arranged in a manner different than that found in nature.

“Endogenous gene” refers to a native gene in its natural location in the genome of an organism. A “foreign-gene” refers to a gene not normally found in the host organism, but that is introduced into the host organism by gene transfer. Foreign genes can comprise native genes inserted into a non-native organism, or chimeric genes. A “transgene” is a gene that has been introduced into the genome by a transformation procedure.

“Coding sequence” refers to a nucleotide sequence that codes for a specific amino acid sequence. “Regulatory sequences” refer to nucleotide sequences located upstream (5' non-coding sequences), within, or downstream (3' non-coding sequences) of a coding sequence, and which influence the transcription, RNA processing or stability, or translation of the associated coding sequence. Regulatory sequences may include promoters, translation leader sequences, introns, and polyadenylation recognition sequences.

“Promoter” refers to a nucleotide sequence capable of controlling the expression of a coding sequence or functional RNA. In general, a coding sequence is located 3' to a promoter sequence. The promoter sequence consists of proximal and more distal upstream elements, the latter elements often referred to as enhancers. Accordingly, an “enhancer” is a nucleotide sequence which can stimulate promoter activity and may be an innate element of the promoter or a heterologous element inserted to enhance the level or tissue-specificity of a promoter. Promoters may be derived in their entirety from a native gene, or may be composed of different elements derived from different promoters found in nature, or may even comprise synthetic nucleotide segments. It is understood by those skilled in the art that different promoters may direct the expression of a gene in different tissues or cell types, or at different stages of development, or in response to different environmental conditions. Promoters which cause a nucleic acid fragment to be expressed in most cell types at most times are commonly referred to as “constitutive promoters”. New promoters of various types useful in plant cells are constantly being discovered; numerous examples may be found in the compilation by Okamuro and Goldberg (1989) *Biochemistry of Plants* 15:1-82. It is further recognized that since in most cases the exact boundaries of regulatory sequences have not been completely defined, nucleic acid fragments of different lengths may have identical promoter activity.

“Translation leader sequence” refers to a nucleotide sequence located between the promoter sequence of a gene and the coding sequence. The translation leader sequence is present in the fully processed mRNA upstream of the translation start sequence. The translation leader sequence may affect processing of the primary transcript to mRNA, mRNA stability or translation efficiency. Examples of translation leader sequences have been described (Turner and Foster (1995) *Mol. Biotechnol.* 3:225-236).

“3' non-coding sequences” refer to nucleotide sequences located downstream of a coding sequence and include polyadenylation recognition sequences and other sequences encoding regulatory signals capable of affecting mRNA processing or gene expression. The polyadenylation signal is usually characterized by affecting the addition of polyadenylic acid tracts to the 3' end of the mRNA precursor. The use of different 3' non-coding sequences is exemplified by Ingelbrecht et al. (1989) *Plant Cell* 1:671-680.

“RNA transcript” refers to the product resulting from RNA polymerase-catalyzed transcription of a DNA sequence. When the RNA transcript is a perfect complementary

copy of the DNA sequence, it is referred to as the primary transcript or it may be a RNA sequence derived from posttranscriptional processing of the primary transcript and is referred to as the mature RNA. "Messenger RNA (mRNA)" refers to the RNA that is without introns and that can be translated into polypeptides by the cell. "cDNA" refers to DNA that is complementary to and derived from an mRNA template. The cDNA can be single-stranded or converted to double stranded form using, for example, the Klenow fragment of DNA polymerase I. "Sense-RNA" refers to an RNA transcript that includes the mRNA and so can be translated into a polypeptide by the cell. "Antisense RNA" refers to an RNA transcript that is complementary to all or part of a target primary transcript or mRNA and that blocks the expression of a target gene (see U.S. Patent No. 5,107,065, incorporated herein by reference). The complementarity of an antisense RNA may be with any part of the specific nucleotide sequence, i.e., at the 5' non-coding sequence, 3' non-coding sequence, introns, or the coding sequence. "Functional RNA" refers to sense RNA, antisense RNA, ribozyme RNA, or other RNA that may not be translated but yet has an effect on cellular processes.

The term "operably linked" refers to the association of two or more nucleic acid fragments on a single polynucleotide so that the function of one is affected by the other. For example, a promoter is operably linked with a coding sequence when it is capable of affecting the expression of that coding sequence (i.e., that the coding sequence is under the transcriptional control of the promoter). Coding sequences can be operably linked to regulatory sequences in sense or antisense orientation.

The term "expression", as used herein, refers to the transcription and stable accumulation of sense (mRNA) or antisense RNA derived from the nucleic acid fragment of the invention. Expression may also refer to translation of mRNA into a polypeptide.

"Antisense inhibition" refers to the production of antisense RNA transcripts capable of suppressing the expression of the target protein. "Overexpression" refers to the production of a gene product in transgenic organisms that exceeds levels of production in normal or non-transformed organisms. "Co-suppression" refers to the production of sense RNA transcripts capable of suppressing the expression of identical or substantially similar foreign or endogenous genes (U.S. Patent No. 5,231,020, incorporated herein by reference).

A "protein" or "polypeptide" is a chain of amino acids arranged in a specific order determined by the coding sequence in a polynucleotide encoding the polypeptide. Each protein or polypeptide has a unique function.

"Altered levels" or "altered expression" refers to the production of gene product(s) in transgenic organisms in amounts or proportions that differ from that of normal or non-transformed organisms.

“Null mutant” refers here to a host cell which either lacks the expression of a certain polypeptide or expresses a polypeptide which is inactive or does not have any detectable expected enzymatic function.

“Mature protein” or the term “mature” when used in describing a protein refers to a post-translationally processed polypeptide; i.e., one from which any pre- or propeptides present in the primary translation product have been removed. “Precursor protein” or the term “precursor” when used in describing a protein refers to the primary product of translation of mRNA; i.e., with pre- and propeptides still present. Pre- and propeptides may be but are not limited to intracellular localization signals.

A “chloroplast transit peptide” is an amino acid sequence which is translated in conjunction with a protein and directs the protein to the chloroplast or other plastid types present in the cell in which the protein is made. “Chloroplast transit sequence” refers to a nucleotide sequence that encodes a chloroplast transit peptide. A “signal peptide” is an amino acid sequence which is translated in conjunction with a protein and directs the protein to the secretory system (Chrispeels (1991) *Ann. Rev. Plant Phys. Plant Mol. Biol.* 42:21-53). If the protein is to be directed to a vacuole, a vacuolar targeting signal (*supra*) can further be added, or if to the endoplasmic reticulum, an endoplasmic reticulum retention signal (*supra*) may be added. If the protein is to be directed to the nucleus, any signal peptide present should be removed and instead a nuclear localization signal included (Raikhel (1992) *Plant Phys.* 100:1627-1632).

“Transformation” refers to the transfer of a nucleic acid fragment into the genome of a host organism, resulting in genetically stable inheritance. Host organisms containing the transformed nucleic acid fragments are referred to as “transgenic” organisms. Examples of methods of plant transformation include *Agrobacterium*-mediated transformation (De Blaere et al. (1987) *Meth. Enzymol.* 143:277) and particle-accelerated or “gene gun” transformation technology (Klein et al. (1987) *Nature (London)* 327:70-73; U.S. Patent No. 4,945,050, incorporated herein by reference). Thus, isolated polynucleotides of the present invention can be incorporated into recombinant constructs, typically DNA constructs, capable of introduction into and replication in a host cell. Such a construct can be a vector that includes a replication system and sequences that are capable of transcription and translation of a polypeptide-encoding sequence in a given host cell. A number of vectors suitable for stable transfection of plant cells or for the establishment of transgenic plants have been described in, e.g., Pouwels et al., *Cloning Vectors: A Laboratory Manual*, 1985, supp. 1987; Weissbach and Weissbach, *Methods for Plant Molecular Biology*, Academic Press, 1989; and Flevin et al., *Plant Molecular Biology Manual*, Kluwer Academic Publishers, 1990. Typically, plant expression vectors include, for example, one or more cloned plant genes under the transcriptional control of 5' and 3' regulatory sequences and a dominant selectable marker. Such plant expression vectors also can contain a promoter regulatory region (e.g., a

regulatory region controlling inducible or constitutive, environmentally- or developmentally-regulated, or cell- or tissue-specific expression), a transcription initiation start site, a ribosome binding site, an RNA processing signal, a transcription termination site, and/or a polyadenylation signal.

5 Standard recombinant DNA and molecular cloning techniques used herein are well known in the art and are described more fully in Sambrook et al. *Molecular Cloning: A Laboratory Manual*; Cold Spring Harbor Laboratory Press: Cold Spring Harbor, 1989 (hereinafter "Maniatis").

10 "PCR" or "polymerase chain reaction" is well known by those skilled in the art as a technique used for the amplification of specific DNA segments (U.S. Patent Nos. 4,683,195 and 4,800,159).

 The present invention concerns an isolated polynucleotide comprising a nucleotide sequence selected from the group consisting of: (a) a first nucleotide sequence encoding a polypeptide of at least 50 amino acids having at least 70% identity based on the Clustal
15 method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:2, 4, and 12, (b) a second nucleotide sequence encoding a polypeptide of at least 100 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:14, 16, 18, and 20, (c) a third nucleotide sequence encoding a polypeptide of at least 180 amino
20 acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:24, (d) a fourth nucleotide sequence encoding a polypeptide of at least 230 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:22, (e) a fifth nucleotide
25 sequence encoding a polypeptide of at least 100 amino acids having at least 80% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:6, 8, and 10, and (f) a sixth nucleotide sequence comprising the complement of (a), (b), (c), (d), or (e).

 Preferably, the first nucleotide sequence comprises a nucleic acid sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23, that
30 codes for the polypeptide selected from the group consisting of SEQ ID NOs:2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24.

 Nucleic acid fragments encoding at least a portion of several WUS proteins have been isolated and identified by comparison of random plant cDNA sequences to public databases containing nucleotide and protein sequences using the BLAST algorithms well
35 known to those skilled in the art. The nucleic acid fragments of the instant invention may be used to isolate cDNAs and genes encoding homologous proteins from the same or other plant species. Isolation of homologous genes using sequence-dependent protocols is well known in the art. Examples of sequence-dependent protocols include, but are not limited to,

methods of nucleic acid hybridization, and methods of DNA and RNA amplification as exemplified by various uses of nucleic acid amplification technologies (e.g., polymerase chain reaction, ligase chain reaction).

For example, genes encoding other WUS proteins, either as cDNAs or genomic
5 DNAs, could be isolated directly by using all or a portion of the instant nucleic acid fragments as DNA hybridization probes to screen libraries from any desired plant employing methodology well known to those skilled in the art. Specific oligonucleotide probes based upon the instant nucleic acid sequences can be designed and synthesized by methods known in the art (Maniatis). Moreover, an entire sequence can be used directly to synthesize DNA
10 probes by methods known to the skilled artisan such as random primer DNA labeling, nick translation, end-labeling techniques, or RNA probes using available *in vitro* transcription systems. In addition, specific primers can be designed and used to amplify a part or all of the instant sequences. The resulting amplification products can be labeled directly during amplification reactions or labeled after amplification reactions, and used as probes to isolate
15 full length cDNA or genomic fragments under conditions of appropriate stringency.

In addition, two short segments of the instant nucleic acid fragments may be used in polymerase chain reaction protocols to amplify longer nucleic acid fragments encoding homologous genes from DNA or RNA. The polymerase chain reaction may also be performed on a library of cloned nucleic acid fragments wherein the sequence of one primer
20 is derived from the instant nucleic acid fragments, and the sequence of the other primer takes advantage of the presence of the polyadenylic acid tracts to the 3' end of the mRNA precursor encoding plant genes. Alternatively, the second primer sequence may be based upon sequences derived from the cloning vector. For example, the skilled artisan can follow the RACE protocol (Frohman et al. (1988) *Proc. Natl. Acad. Sci. USA* 85:8998-9002) to
25 generate cDNAs by using PCR to amplify copies of the region between a single point in the transcript and the 3' or 5' end. Primers oriented in the 3' and 5' directions can be designed from the instant sequences. Using commercially available 3' RACE or 5' RACE systems (BRL), specific 3' or 5' cDNA fragments can be isolated (Ohara et al. (1989) *Proc. Natl. Acad. Sci. USA* 86:5673-5677; Loh et al. (1989) *Science* 243:217-220). Products generated
30 by the 3' and 5' RACE procedures can be combined to generate full-length cDNAs (Frohman and Martin (1989) *Techniques* 1:165). Consequently, a polynucleotide comprising a nucleotide sequence of at least one of 60 (preferably one of at least 40, most preferably one of at least 30) contiguous nucleotides derived from a nucleotide sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23 and the
35 complement of such nucleotide sequences may be used in such methods to obtain a nucleic acid fragment encoding a substantial portion of an amino acid sequence of a polypeptide.

The present invention relates to a method of obtaining a nucleic acid fragment encoding a substantial portion of a WUS polypeptide, preferably a substantial portion of a

plant WUS polypeptide, comprising the steps of : synthesizing an oligonucleotide primer comprising a nucleotide sequence of at least one of 60 (preferably at least one of 40, most preferably at least one of 30) contiguous nucleotides derived from a nucleotide sequence selected from the group consisting of SEQ ID NOs:1, 3, 5, 7, 9, 11, 13, 15, 17, 19, 21, and 23, and the complement of such nucleotide sequences; and amplifying a nucleic acid fragment (preferably a cDNA inserted in a cloning vector) using the oligonucleotide primer. The amplified nucleic acid fragment preferably will encode a portion of a WUS polypeptide.

Availability of the instant nucleotide and deduced amino acid sequences facilitates immunological screening of cDNA expression libraries. Synthetic peptides representing portions of the instant amino acid sequences may be synthesized. These peptides can be used to immunize animals to produce polyclonal or monoclonal antibodies with specificity for peptides or proteins comprising the amino acid sequences. These antibodies can be then be used to screen cDNA expression libraries to isolate full-length cDNA clones of interest (Lerner (1984) *Adv. Immunol.* 36:1-34; Maniatis).

In another embodiment, this invention concerns viruses and host cells comprising either the chimeric genes of the invention as described herein or an isolated polynucleotide of the invention as described herein. Examples of host cells which can be used to practice the invention include, but are not limited to, yeast, bacteria, and plants.

As was noted above, the nucleic acid fragments of the instant invention may be used to create transgenic plants in which the disclosed polypeptides are present at higher or lower levels than normal or in cell types or developmental stages in which they are not normally found. This would have the effect of altering development (e.g., the initiation and maintenance of meristem apical initials) in those plants.

Overexpression of the proteins of the instant invention may be accomplished by first constructing a chimeric gene in which the coding region is operably linked to a promoter capable of directing expression of a gene in the desired tissues at the desired stage of development. The chimeric gene may comprise promoter sequences and translation leader sequences derived from the same genes. 3' Non-coding sequences encoding transcription termination signals may also be provided. The instant chimeric gene may also comprise one or more introns in order to facilitate gene expression.

Plasmid vectors comprising the instant isolated polynucleotide (or chimeric gene) may be constructed. The choice of plasmid vector is dependent upon the method that will be used to transform host plants. The skilled artisan is well aware of the genetic elements that must be present on the plasmid vector in order to successfully transform, select and propagate host cells containing the chimeric gene. The skilled artisan will also recognize that different independent transformation events will result in different levels and patterns of expression (Jones et al. (1985) *EMBO J.* 4:2411-2418; De Almeida et al. (1989) *Mol. Gen. Genetics* 218:78-86), and thus that multiple events must be screened in order to obtain lines

displaying the desired expression level and pattern. Such screening may be accomplished by Southern analysis of DNA, Northern analysis of mRNA expression, Western analysis of protein expression, or phenotypic analysis.

For some applications it may be useful to direct the instant polypeptides to different cellular compartments, or to facilitate its secretion from the cell. It is thus envisioned that the chimeric gene described above may be further supplemented by directing the coding sequence to encode the instant polypeptides with appropriate intracellular targeting sequences such as transit sequences (Keegstra (1989) *Cell* 56:247-253), signal sequences or sequences encoding endoplasmic reticulum localization (Chrispeels (1991) *Ann. Rev. Plant Phys. Plant Mol. Biol.* 42:21-53), or nuclear localization signals (Raikhel (1992) *Plant Phys.* 100:1627-1632) with or without removing targeting sequences that are already present. While the references cited give examples of each of these, the list is not exhaustive and more targeting signals of use may be discovered in the future.

It may also be desirable to reduce or eliminate expression of genes encoding the instant polypeptides in plants for some applications. In order to accomplish this, a chimeric gene designed for co-suppression of the instant polypeptide can be constructed by linking a gene or gene fragment encoding that polypeptide to plant promoter sequences. Alternatively, a chimeric gene designed to express antisense RNA for all or part of the instant nucleic acid fragment can be constructed by linking the gene or gene fragment in reverse orientation to plant promoter sequences. Either the co-suppression or antisense chimeric genes could be introduced into plants via transformation wherein expression of the corresponding endogenous genes are reduced or eliminated.

Molecular genetic solutions to the generation of plants with altered gene expression have a decided advantage over more traditional plant breeding approaches. Changes in plant phenotypes can be produced by specifically inhibiting expression of one or more genes by antisense inhibition or cosuppression (U.S. Patent Nos. 5,190,931, 5,107,065 and 5,283,323). An antisense or cosuppression construct would act as a dominant negative regulator of gene activity. While conventional mutations can yield negative regulation of gene activity these effects are most likely recessive. The dominant negative regulation available with a transgenic approach may be advantageous from a breeding perspective. In addition, the ability to restrict the expression of a specific phenotype to the reproductive tissues of the plant by the use of tissue specific promoters may confer agronomic advantages relative to conventional mutations which may have an effect in all tissues in which a mutant gene is ordinarily expressed.

The person skilled in the art will know that special considerations are associated with the use of antisense or cosuppression technologies in order to reduce expression of particular genes. For example, the proper level of expression of sense or antisense genes may require the use of different chimeric genes utilizing different regulatory elements known to the

skilled artisan. Once transgenic plants are obtained by one of the methods described above, it will be necessary to screen individual transgenics for those that most effectively display the desired phenotype. Accordingly, the skilled artisan will develop methods for screening large numbers of transformants. The nature of these screens will generally be chosen on practical grounds. For example, one can screen by looking for changes in gene expression by using antibodies specific for the protein encoded by the gene being suppressed, or one could establish assays that specifically measure enzyme activity. A preferred method will be one which allows large numbers of samples to be processed rapidly, since it will be expected that a large number of transformants will be negative for the desired phenotype.

In another embodiment, the present invention concerns an isolated polypeptide selected from the group consisting of: (a) a polypeptide of at least 50 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:2, 4, and 12, (b) a polypeptide of at least 100 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:14, 16, 18, and 20, (c) a polypeptide of at least 180 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:24, (d) a polypeptide of at least 230 amino acids having at least 70% identity based on the Clustal method of alignment when compared to a polypeptide of SEQ ID NO:22, and (e) a polypeptide of at least 100 amino acids having at least 80% identity based on the Clustal method of alignment when compared to a polypeptide selected from the group consisting of SEQ ID NOs:6, 8, and 10.

The instant polypeptides (or portions thereof) may be produced in heterologous host cells, particularly in the cells of microbial hosts, and can be used to prepare antibodies to these proteins by methods well known to those skilled in the art. The antibodies are useful for detecting the polypeptides of the instant invention *in situ* in cells or *in vitro* in cell extracts. Preferred heterologous host cells for production of the instant polypeptides are microbial hosts. Microbial expression systems and expression vectors containing regulatory sequences that direct high level expression of foreign proteins are well known to those skilled in the art. Any of these could be used to construct a chimeric gene for production of the instant polypeptides. This chimeric gene could then be introduced into appropriate microorganisms via transformation to provide high level expression of the encoded WUS protein. An example of a vector for high level expression of the instant polypeptides in a bacterial host is provided (Example 12).

All or a substantial portion of the polynucleotides of the instant invention may also be used as probes for genetically and physically mapping the genes that they are a part of, and used as markers for traits linked to those genes. Such information may be useful in plant breeding in order to develop lines with desired phenotypes. For example, the instant

nucleic acid fragments may be used as restriction fragment length polymorphism (RFLP) markers. Southern blots (Maniatis) of restriction-digested plant genomic DNA may be probed with the nucleic acid fragments of the instant invention. The resulting banding patterns may then be subjected to genetic analyses using computer programs such as MapMaker (Lander et al. (1987) *Genomics* 1:174-181) in order to construct a genetic map. In addition, the nucleic acid fragments of the instant invention may be used to probe Southern blots containing restriction endonuclease-treated genomic DNAs of a set of individuals representing parent and progeny of a defined genetic cross. Segregation of the DNA polymorphisms is noted and used to calculate the position of the instant nucleic acid sequence in the genetic map previously obtained using this population (Botstein et al. (1980) *Am. J. Hum. Genet.* 32:314-331).

The production and use of plant gene-derived probes for use in genetic mapping is described in Bernatzky and Tanksley (1986) *Plant Mol. Biol. Reporter* 4:37-41. Numerous publications describe genetic mapping of specific cDNA clones using the methodology outlined above or variations thereof. For example, F2 intercross populations, backcross populations, randomly mated populations, near isogenic lines, and other sets of individuals may be used for mapping. Such methodologies are well known to those skilled in the art.

Nucleic acid probes derived from the instant nucleic acid sequences may also be used for physical mapping (i.e., placement of sequences on physical maps; see Hoheisel et al. In: *Nonmammalian Genomic Analysis: A Practical Guide*, Academic press 1996, pp. 319-346, and references cited therein).

In another embodiment, nucleic acid probes derived from the instant nucleic acid sequences may be used in direct fluorescence *in situ* hybridization (FISH) mapping (Trask (1991) *Trends Genet.* 7:149-154). Although current methods of FISH mapping favor use of large clones (several to several hundred KB; see Laan et al. (1995) *Genome Res.* 5:13-20), improvements in sensitivity may allow performance of FISH mapping using shorter probes.

A variety of nucleic acid amplification-based methods of genetic and physical mapping may be carried out using the instant nucleic acid sequences. Examples include allele-specific amplification (Kazazian (1989) *J. Lab. Clin. Med.* 11:95-96), polymorphism of PCR-amplified fragments (CAPS; Sheffield et al. (1993) *Genomics* 16:325-332), allele-specific ligation (Landegren et al. (1988) *Science* 241:1077-1080), nucleotide extension reactions (Sokolov (1990) *Nucleic Acid Res.* 18:3671), Radiation Hybrid Mapping (Walter et al. (1997) *Nat. Genet.* 7:22-28) and Happy Mapping (Dear and Cook (1989) *Nucleic Acid Res.* 17:6795-6807). For these methods, the sequence of a nucleic acid fragment is used to design and produce primer pairs for use in the amplification reaction or in primer extension reactions. The design of such primers is well known to those skilled in the art. In methods employing PCR-based genetic mapping, it may be necessary to identify DNA sequence differences between the parents of the mapping cross in the region corresponding to the

instant nucleic acid sequence. This, however, is generally not necessary for mapping methods.

Loss of function mutant phenotypes may be identified for the instant cDNA clones either by targeted gene disruption protocols or by identifying specific mutants for these genes contained in a maize population carrying mutations in all possible genes (Ballinger and Benzer (1989) *Proc. Natl. Acad. Sci USA* 86:9402-9406; Koes et al. (1995) *Proc. Natl. Acad. Sci USA* 92:8149-8153; Bensen et al. (1995) *Plant Cell* 7:75-84). The latter approach may be accomplished in two ways. First, short segments of the instant nucleic acid fragments may be used in polymerase chain reaction protocols in conjunction with a mutation tag sequence primer on DNAs prepared from a population of plants in which Mutator transposons or some other mutation-causing DNA element has been introduced (see Bensen, *supra*). The amplification of a specific DNA fragment with these primers indicates the insertion of the mutation tag element in or near the plant gene encoding the instant polypeptide. Alternatively, the instant nucleic acid fragment may be used as a hybridization probe against PCR amplification products generated from the mutation population using the mutation tag sequence primer in conjunction with an arbitrary genomic site primer, such as that for a restriction enzyme site-anchored synthetic adaptor. With either method, a plant containing a mutation in the endogenous gene encoding the instant polypeptide can be identified and obtained. This mutant plant can then be used to determine or confirm the natural function of the instant polypeptides disclosed herein.

EXAMPLES

The present invention is further defined in the following Examples, in which parts and percentages are by weight and degrees are Celsius, unless otherwise stated. It should be understood that these Examples, while indicating preferred embodiments of the invention, are given by way of illustration only. From the above discussion and these Examples, one skilled in the art can ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions. Thus, various modifications of the invention in addition to those shown and described herein will be apparent to those skilled in the art from the foregoing description. Such modifications are also intended to fall within the scope of the appended claims.

The disclosure of each reference set forth herein is incorporated herein by reference in its entirety.

EXAMPLE 1

Composition of cDNA Libraries; Isolation and Sequencing of cDNA Clones

cDNA libraries representing mRNAs from various corn (*Zea mays*) and soybean (*Glycine max*) tissues were prepared. The characteristics of the libraries are described below.

TABLE 2
cDNA Libraries from Corn and Soybean

Library	Tissue	Clone
cpglc	Corn Pooled BMS Treated with Chemicals Related to RNA, DNA Synthesis*	cpglc.pk006.b16
cpilc	Corn Pooled BMS Treated with Chemicals Related to Biochemical Compound Synthesis**	cpilc.pk012.p19
p0016	Corn Tassel Shoots, Pooled, 0.1-1.4 cm	p0016.ctsas50r
p0058	Sweet Corn Hybrid (Honey N Pearl) Shoot Culture	p0058.chpab57r
p0083	Corn Whole Kernels 7 Days After Pollination	p0083.cldev71r
scr1c	Soybean Embryogenic Suspension Culture Subjected to 4 Vacuum Cycles and Collected 12 Hrs Later	scr1c.pk001.d2
ses4d	Soybean Embryogenic Suspension 4 Days After Subculture	ses4d.pk0033.c8
sgs5c	Soybean Seeds 4 Days After Germination	sgs5c.pk0002.f2
ssm	Soybean Shoot Meristem	ssm.pk0060.h4

*Chemicals used included hydroxyurea, aphidicolin, HC-toxin, actinomycin D, all of which are commercially available from Calbiochem-Novabiochem Corp. (1-800-628-8470)

**Chemicals used included sorbitol, egosterol, taxifolin, methotrexate, D-mannose, D-glucose, alpha-amino adipic acid, ancymidol, all of which are commercially available from Calbiochem-Novabiochem Corp. (1-800-628-8470)

cDNA libraries may be prepared by any one of many methods available. For example, the cDNAs may be introduced into plasmid vectors by first preparing the cDNA libraries in Uni-ZAP™ XR vectors according to the manufacturer's protocol (Stratagene Cloning Systems, La Jolla, CA). The Uni-ZAP™ XR libraries are converted into plasmid libraries according to the protocol provided by Stratagene. Upon conversion, cDNA inserts will be contained in the plasmid vector pBluescript. In addition, the cDNAs may be introduced directly into precut Bluescript II SK(+) vectors (Stratagene) using T4 DNA ligase (New England Biolabs), followed by transfection into DH10B cells according to the manufacturer's protocol (GIBCO BRL Products). Once the cDNA inserts are in plasmid vectors, plasmid DNAs are prepared from randomly picked bacterial colonies containing recombinant pBluescript plasmids, or the insert cDNA sequences are amplified via polymerase chain reaction using primers specific for vector sequences flanking the inserted cDNA sequences. Amplified insert DNAs or plasmid DNAs are sequenced in dye-primer sequencing reactions to generate partial cDNA sequences (expressed sequence tags or "ESTs"; see Adams et al., (1991) *Science* 252:1651-1656). The resulting ESTs are analyzed using a Perkin Elmer Model 377 fluorescent sequencer.

Full-insert sequence (FIS) data is generated utilizing a modified transposition protocol. Clones identified for FIS are recovered from archived glycerol stocks as single colonies, and plasmid DNAs are isolated via alkaline lysis. Isolated DNA templates are reacted with vector primed M13 forward and reverse oligonucleotides in a PCR-based sequencing reaction and loaded onto automated sequencers. Confirmation of clone identification is performed by sequence alignment to the original EST sequence from which the FIS request is made.

Confirmed templates are transposed via the Primer Island transposition kit (PE Applied Biosystems, Foster City, CA) which is based upon the *Saccharomyces cerevisiae* Ty1 transposable element (Devine and Boeke (1994) *Nucleic Acids Res.* 22:3765-3772). The *in vitro* transposition system places unique binding sites randomly throughout a population of large DNA molecules. The transposed DNA is then used to transform DH10B electro-competent cells (Gibco BRL/Life Technologies, Rockville, MD) via electroporation. The transposable element contains an additional selectable marker (named DHFR; Fling and Richards (1983) *Nucleic Acids Res.* 11:5147-5158), allowing for dual selection on agar plates of only those subclones containing the integrated transposon. Multiple subclones are randomly selected from each transposition reaction, plasmid DNAs are prepared via alkaline lysis, and templates are sequenced (ABI Prism dye-terminator ReadyReaction mix) outward from the transposition event site, utilizing unique primers specific to the binding sites within the transposon.

Sequence data is collected (ABI Prism Collections) and assembled using Phred/Phrap (P. Green, University of Washington, Seattle). Phrep/Phrap is a public domain software program which re-reads the ABI sequence data, re-calls the bases, assigns quality values, and writes the base calls and quality values into editable output files. The Phrap sequence assembly program uses these quality values to increase the accuracy of the assembled sequence contigs. Assemblies are viewed by the Consed sequence editor (D. Gordon, University of Washington, Seattle).

EXAMPLE 2

Identification of cDNA Clones

cDNA clones encoding WUS protein were identified by conducting BLAST (Basic Local Alignment Search Tool; Altschul et al. (1993) *J. Mol. Biol.* 215:403-410; see also www.ncbi.nlm.nih.gov/BLAST/) searches for similarity to sequences contained in the BLAST "nr" database (comprising all non-redundant GenBank CDS translations, sequences derived from the 3-dimensional structure Brookhaven Protein Data Bank, the last major release of the SWISS-PROT protein sequence database, EMBL, and DDBJ databases). The cDNA sequences obtained in Example 1 were analyzed for similarity to all publicly available DNA sequences contained in the "nr" database using the BLASTN algorithm provided by the National Center for Biotechnology Information (NCBI). The DNA

sequences were translated in all reading frames and compared for similarity to all publicly available protein sequences contained in the "nr" database using the BLASTX algorithm (Gish and States (1993) *Nat. Genet.* 3:266-272) provided by the NCBI. For convenience, the P-value (probability) of observing a match of a cDNA sequence to a sequence contained in the searched databases merely by chance as calculated by BLAST are reported herein as "pLog" values, which represent the negative of the logarithm of the reported P-value. Accordingly, the greater the pLog value, the greater the likelihood that the cDNA sequence and the BLAST "hit" represent homologous proteins.

ESTs submitted for analysis are compared to the genbank database as described above. ESTs that contain sequences more 5- or 3-prime can be found by using the BLASTn algorithm (Altschul et al (1997) *Nucleic Acids Res.* 25:3389-3402.) against the Du Pont proprietary database comparing nucleotide sequences that share common or overlapping regions of sequence homology. Where common or overlapping sequences exist between two or more nucleic acid fragments, the sequences can be assembled into a single contiguous nucleotide sequence, thus extending the original fragment in either the 5 or 3 prime direction. Once the most 5-prime EST is identified, its complete sequence can be determined by Full Insert Sequencing as described in Example 1. Homologous genes belonging to different species can be found by comparing the amino acid sequence of a known gene (from either a proprietary source or a public database) against an EST database using the tBLASTn algorithm. The tBLASTn algorithm searches an amino acid query against a nucleotide database that is translated in all 6 reading frames. This search allows for differences in nucleotide codon usage between different species, and for codon degeneracy.

EXAMPLE 3

Characterization of cDNA Clones Encoding WUS Protein Homologs

The BLASTX search using the EST sequences from clones listed in Table 3 revealed similarity of the polypeptides encoded by the cDNAs to WUS proteins from *Arabidopsis thaliana* (NCBI GenBank Identifier (GI) No. 3785979) and *Arabidopsis thaliana* (NCBI GI No. 4090200). Shown in Table 3 are the BLAST results for individual ESTs ("EST"), the sequences of the entire cDNA inserts comprising the indicated cDNA clones ("FIS"), or contigs assembled from two or more ESTs ("Contig"):

TABLE 3

BLAST Results for Sequences Encoding Polypeptides Homologous
to *Arabidopsis thaliana* WUS Proteins

Clone	Status	BLAST pLog Score
Contig composed of: cpg1c.pk006.b16 cpi1c.pk012.p19	Contig	14.30 (NCBI GI No.3785979)
p0016.ctsas50r	EST	31.00 (NCBI GI No.4090200)
p0083.cldev71r	EST	17.40 (NCBI GI No. 3785979)
Contig composed of: scr1c.pk001.d2 ses4d.pk0033.c8	Contig	24.52 (NCBI GI No. 3785979)

The data in Table 4 represents a calculation of the percent identity of the amino acid sequences set forth in SEQ ID NOs:2, 6, 12 and 16 and the *Arabidopsis thaliana* (NCBI GI No. 3785979) and (NCBI GI No. 4090200) sequences (SEQ ID NOs:27 and 28 respectively). The percent identity between the amino acid sequences set forth in SEQ ID NOs: 2, 6, 12 and 16 ranged from 35-40%.

TABLE 4

Percent Identity of Amino Acid Sequences Deduced From the Nucleotide Sequences of
cDNA Clones Encoding Polypeptides Homologous to *Arabidopsis thaliana* WUS Proteins

SEQ ID NO.	Percent Identity to
2	43% (NCBI GI No. 3785979)
6	45% (NCBI GI No. 4090200)
12	37% (NCBI GI No. 3785979)
16	37% (NCBI GI No. 3785979)

The sequence of the entire cDNA insert in most of the clones listed in Table 3 was determined. Further sequencing and searching of the DuPont proprietary database allowed the identification of other corn and soybean clones encoding WUS protein. The BLASTX search using the EST sequences from clones listed in Table 5 revealed similarity of the polypeptides encoded by the cDNAs to WUS proteins from *Arabidopsis thaliana* (NCBI GI Nos. 3785979, 4090200, 4580396, 9294502 and 6091768) and *Oryza sativa* (NCBI GI No. 8099120). Shown in Table 5 are the BLAST results for individual ESTs ("EST"), the sequences of the entire cDNA inserts comprising the indicated cDNA clones ("FIS"), sequences of contigs assembled from two or more ESTs ("Contig"), sequences of contigs assembled from an FIS and one or more ESTs or PCR fragment sequence ("Contig*"), or sequences encoding the entire protein derived from an EST, an FIS, a contig, or an FIS and PCR fragment sequence ("CGS"):

TABLE 5
BLAST Results for Sequences Encoding Polypeptides Homologous
to WUS Proteins

Clone	Status	BLAST Results	
		NCBI GI No.	BLAST pLog Score
cpi1c.pk012.p19 (FIS)	CGS	3785979	21.30
p0016.ctsas50r	FIS	4090200	27.00
p0058.chpab57r (FIS)	CGS	6091768	36.52
p0083.cldev71r	FIS	4580396	15.70
scr1c.pk001.d2	FIS	3785979	20.04
ses4d.pk0033.c8 (FIS)	CGS	3785979	21.10
sgs5c.pk0002.f2 (EST)	CGS	8099120	23.70
Contig of	CGS	9294502	23.00
ssm.pk0060.h4 (FIS)			
NCBI GI No. 4395781			

5 Figure 1 presents an alignment of the amino acid sequences set forth in SEQ ID
NOs:4, 10, 20, 22, and 24 and the *Arabidopsis thaliana* sequence (NCBI GI No. 4090200;
SEQ ID NO:25). The data in Table 6 represents a calculation of the percent identity of the
amino acid sequences set forth in SEQ ID NOs:4, 10, 20, 22, and 24 and the *Arabidopsis*
10 *thaliana* sequence (NCBI GI No. 4090200; SEQ ID NO:25).

TABLE 6
Percent Identity of Amino Acid Sequences Deduced From the Nucleotide Sequences
of cDNA Clones Encoding Polypeptides Homologous to WUS Protein

SEQ ID NO.	Percent Identity to	
	NCBI GI No. 4090200; SEQ ID NO:25	
4	22.7	
10	18.2	
20	25.0	
22	21.6	
24	22.2	

15 Sequence alignments and percent identity calculations were performed using the
Megalign program of the LASERGENE bioinformatics computing suite (DNASTAR Inc.,
Madison, WI). Multiple alignment of the sequences was performed using the Clustal
method of alignment (Higgins and Sharp (1989) *CABIOS*. 5:151-153) with the default
parameters (GAP PENALTY=10, GAP LENGTH PENALTY=10). Default parameters for
pairwise alignments using the Clustal method were KTUPLE 1, GAP PENALTY=3,
20 WINDOW=5 and DIAGONALS SAVED=5. Sequence alignments and BLAST scores and
probabilities indicate that the nucleic acid fragments comprising the instant cDNA clones

encode a substantial portion of a WUS protein. These sequences represent the first corn and soybean sequences encoding WUS proteins known to Applicant.

EXAMPLE 4

Sunflower Meristem Transformation

5 There are a number of published examples of meristem transformation systems for dicot species including soybean (McCabe et al, 1988), sunflower (Bidney et al., 1992), and cotton (Gould et al., 1998), where chimeric genes are delivered to cells of the meristem and then participate in formation of shoots, reproductive structures and ultimately seed. Transgene delivery is accomplished by both standard particle bombardment protocols as
10 described for soybean or by T-DNA and *Agrobacterium* protocols as described for sunflower and cotton. The WUS gene could be delivered to dicot meristem targets for either stable or transient transformation to impact the transformation response. WUS could be delivered together with agronomic genes or be used as a conditioning treatment prior to or following the protocol for DNA delivery. The methods for sunflower meristem transformation follow.

15 Sunflower meristem transformation is achieved by a protocol for direct DNA delivery by particle bombardment or a protocol involving a combination of DNA-free particle bombardment followed by use of *Agrobacterium* inoculation for DNA delivery as described in Bidney et al., 1992, *Plant Mol. Biol.* 18:301-313. Sunflower line SMF3, described in Burrus et al., 1991, *Plant Cell Rep.* 10:161-166, is used. The explant source is
20 dry sunflower seed that is imbibed and dissected into meristem explants. Seeds are dehulled and surface sterilized then placed in sterile petri plates on two layers of filter paper moistened with sterile distilled water for overnight imbibition in the dark at 26°C in a Perival incubator. The next day, cotyledons and root radicle are removed and meristem explants transferred to 374E medium (MS salts, Shepard vitamins, 40 mg/l adenine sulfate, 3%
25 sucrose, 0.5 mg/l 6-BAP, 0.25 mg/l IAA, 0.1 mg/l GA, pH 5.6, and 0.8% Phytagar). Explants are cultured for 24 hr on 374E medium in the dark at 26°C. Following this culture period, elongated primary leaves were removed to expose the apical meristem. The meristem explants were placed in the center of petri plates with 374M medium (374E with 1.2% Phytagar) in preparation for particle bombardment then back in the dark for another
30 24 hr period at 26°C.

 Particle preparation for the *Agrobacterium* based protocol is done by suspending 18.8 mg of 1.8 μ m tungsten particles or 21.6 mg of 2.0 μ m gold particles in 200 μ l absolute ethanol. Following particle resuspension by sonication and vigorous mixing, 10 μ l of
35 particle suspension is dropped on the center of the surface of macro-carrier. Plates of 374M medium containing sunflower meristem explants are shot twice by a DuPont Biolistics PDS1000 helium gun with vacuum drawn to 26 Hg, with 650 psi rupture discs, and at the top level in the gun. Following particle bombardment, explants are spread out on the 374M plates, inoculated with an *Agrobacterium* suspension and co-cultured in the light at 26°C for

4d. The *Agrobacterium* inoculating suspension is prepared by first starting a 5 ml liquid culture in 60A medium with kanamycin (YEP medium – 10 g/l Bactopeptone, 10 g/l yeast extract, 5 g/l sodium chloride, pH 7.0, and 50 mg/l kanamycin) grown to log phase (OD600 0.5-1.0). The log phase growth *Agrobacterium* suspension is centrifuged at 6K for 5 min and the supernatant discarded. The bacterial pellet is resuspended in inoculation medium (IM) (IM – 12.5 mM MES, 1 g/l ammonium chloride, 0.3 g/l magnesium sulfate, pH 5.7) to a final calculated OD600 vis of 4.0. The inoculating *Agrobacterium* suspension is applied twice using a micro-pipette and 0.5 ul of suspension per explant. After the 4 d co-cultivation of sunflower meristem explants, the expanded bases of explants are trimmed off and they are transferred to 374C medium (374E which lacks hormones, but adds 250 mg/l cefotaxime) and cultured for two weeks in the light under 18 hr day length at 26°C.

Alternatively, a direct DNA delivery protocol can be applied to sunflower meristem explants prepared as described above. Particles are prepared as follows: to 50 µL of a 15 mg/mL 0.6 µm gold particle suspension is added (in order): 10 µL DNA (0.1 µg/µL), 20 µL spermidine (0.1 M), and 50 µL CaCl₂ (2.5 M). The particle preparation is then agitated for three minutes, spun in a microfuge for 10 seconds and the supernatant removed. The DNA-coated particles are then washed once in 500 µL 100% ethanol and resuspended in 30 µL of 100% ethanol. The DNA/particle suspension can be sonicated three times for one second each. Five µL of the DNA-coated gold particles are then loaded on each macro carrier disk. Meristem explants are bombarded as described in the previous paragraph, spread out on 374M medium, and cultured for 4 d in a Percival incubator under 18 hr of daylength at 26°C. The expanded bases of the explant are then cut off and the explant transferred to 374C medium for 2 wk of culture under the long day conditions at 26°C.

After two weeks sunflower shoots emerge from the meristem explants on 374C medium. The shoots can be scored destructively or non-destructively for the frequency of transgenic sectors per experiment and the quality of sectors with longer, wider, and deeper transgenic sectors being more desirable. They can be scored and compared to control using scorable markers such as the GUS enzyme or green fluorescence protein (GFP). Transgenic plants and seed can be obtained by adding steps to the procedure as outlined below. An assay is required such as an enzyme assay or ELISA for an agronomic protein of interest. An example is provided using the enzyme oxalate oxidase as a scorable marker. Chemical selection is not required for this transformation process.

Primary shoots following two weeks of culture on 374C medium are screened using the oxalate oxidase enzyme assay. Oxalate oxidase enzyme assays were set up using fresh leaf or cotyledon tissue to identify transformants. The assay method was done according to the protocol of Suigura, et al., 1979, Chem. Pharm. Bull. 27(9):2003-2007. The assay is a two step reaction in which hydrogen peroxide is generated by oxalate oxidase in the first step then detected quantitatively by a peroxidase linked color reaction in the second. The color

reaction is then measured by spectrophotometer using visible light at 550 nm. The first step of the assay was initiated by grinding shoot derived leaf tissue, pooled leaf tips of 1 sample per shoot, in 0.1 M succinate buffer, pH 3.5. The extracts were centrifuged and supernatants were discarded because most of the enzyme activity is in the cell wall due to the signal peptide of oxalate oxidase. The pellet was resuspended in 0.1 M succinate buffer, pH 3.5, and 0.05 ml of an oxalic acid solution consisting of 10 mM oxalic acid dissolved in 0.1 M succinate buffer, pH 3.5. The oxalate oxidase enzyme reaction proceeded with mild agitation at room temperature (25°C) for 4 hr. At the end of this time period the reactions were centrifuged and an aliquot of the supernatant removed and added to a volume of 1 M Tris, pH unadjusted, to adjust the samples to a final pH of 7.0 (Tris to 0.147 M) for the second reaction step of the assay. Color development was done by adding the following components in 0.2 M Tris HCl, pH 7.0, in a mixture such that listed final concentrations were achieved: horseradish peroxidase (20 µ/ml), 4-aminoantipyrine (0.165 mM), and N,N-dimethylaniline (0.33 mM). Absorbance at 500 nm was read for samples of the color development reaction. Shoots positive for oxalate oxidase activity were moved into nodal culture for plant recovery and the negative shoots were discarded.

Positive shoots were divided into nodal explants where each explant contained at least one node from which a shoot might be recovered. Nodal explants were culture for 3 d on 374G medium (374E plus 250 mg/l cefotaxime) in the light to release nodal meristems then transferred to 374C medium and cultured in the light at 26°C for 4 weeks to allow nodal shoot development. Shoots derived from nodal culture were assayed for oxalate oxidase activity as described above. The oxalate oxidase positive shoots were moved to procedures for plant recovery in the greenhouse and the negatives were discarded.

Assay positive shoots were recovered by grafting to Pioneer sunflower hybrid 6150 grown aseptically and in-vitro on 48 P medium (1/2X MS salts, 0.5% sucrose, pH 5.0, 0.3% gelrite). Root-stock was prepared by surface sterilizing seed of 6150 as described above for SMF3 then imbibing in the light at 26°C for 4 days. Following this initial germination step, seedlings are place in the dark on 48P medium for 4 d to elongate hypocotyls. The seedlings were then placed back into the light and could be used in the next 7-10 days for grafting. Grafting was done by first cutting the 6150 seedling in the hypocotyl region below the meristem then slicing the hypocotyl longitudinally in half at the cut site. Transgenic shoots are cut at their base to separate from the originating explant and secured on the root-stock by using a parafilm wrap. After about one week in-vitro, the grafted plants were transferred to soil and maintained under humid conditions until they could survive in drier air in the greenhouse.

Transformed T0 plants are further characterized by oxalate oxidase activity assays to verify the continued presence of an active transgene and to determine if the transgene would be present in floral tissue. If there is a sector of transformation which did not develop into a

new portion of the growing T0 plant, that plant portion is trimmed off to induce floral bud initiation from axillary meristems. T0 flowers are selfed, T1 seed is recovered, and the T1 seed is germinated for T1 transgenic plant identification. Cotyledon or leaf tissue of T1 seedlings is sampled and used to assay for the scorable transgene.

5

EXAMPLE 5

Ectopic Expression of Soybean WUS to Induce Organogenesis

In addition to testing WUS in meristem transformation, other tissue explants can be tested for the formation of adventive meristems following stable or transient transformation by WUS. The explant types are well known in the art of dicot transformation and might include hypocotyl explants, leaf explants, cotyledon explants, or immature tissues such as embryo or primary leaf as described here for sunflower. As described for meristem explants, the DNA delivery can be done by either the direct delivery of particle bombardment or by *Agrobacterium* delivery by T-DNA. Using sunflower genotype SMF3 as an example, primary leaves are isolated from meristem explants prepared as described above. After the overnight culture of dissected seeds on 374E medium, the primary leaves have elongated. These are removed and placed in the center of sterile petri plates on filters moistened with 530 medium (MS salts, B5 vitamins, 3% sucrose, 4 mg/l p-chlorophenoxyacetic acid, pH 5.8) in preparation for particle bombardment. Primary leaf explants are spread out over the center of these plates such that none are overlapping others. Particle bombardment is done exactly as described above for direct DNA delivery to meristem explants except that a sterile 70 um nitex mesh is placed over the top of the explants to help prevent them from shifting during bombardment. The DNA delivered could include a chimeric gene, consisting of a constitutive promoter such as SCP1 combined with the selectable marker NPTII and the PINII 3' region, that allows for the preferential growth of transformed tissue. Alternatively, the WUS gene may provide a growth advantage to the tissue such that a selectable marker is not required. Following particle bombardment, the explants are cultured for 3d on filters continuously moistened with 530 medium by adding 0.5 mL of additional liquid medium per 24 hr. They are cultured in the Percival growth chamber in the light under 18 hr daylength and at 26°C. Primary leaf explants that have shown growth are then transferred to 374E medium containing 50 mg/l kanamycin if the selectable marker gene was used and cultured for 2 to 3 wk to allow transgenic callus and shoot formation. Cultures that do not respond are transferred every two weeks to 374E with 50 mg/l kanamycin until recoverable shoots are formed. Shoots are sampled, selected, and recovered to the greenhouse as described for meristem explants above.

35

Sunflower primary leaves can be transformed using *Agrobacterium* by slight modifications to the protocols above. The explants on 530 medium are bombarded as described for meristem explants in the *Agrobacterium* procedure above. An *Agrobacterium* suspension is produced exactly as described for meristem explants except that the liquid

culture is 25 ml instead of 5 ml. The *Agrobacterium* cells are centrifuged, the growth medium supernatant discarded, and the cells resuspended to a calculated OD600 of 0.6 in inoculation medium. Primary leaf explants are inoculated in this suspension for 10 min, then placed back on 530 medium and co-cultivated for 3 d under the growth chamber conditions described above. The explants are then transferred to 374D medium (374E, 50 mg/l kanamycin, 250 mg/l cefotaxime) and cultured for 2-3 weeks. Explants can be transferred every two weeks to fresh 374D medium until shoots can be recovered.

EXAMPLE 6

Expression of Chimeric Genes in Monocot Cells

A chimeric gene comprising a cDNA encoding the instant polypeptide in sense orientation with respect to the maize 27 kD zein promoter that is located 5' to the cDNA fragment, and the 10 kD zein 3' end that is located 3' to the cDNA fragment, can be constructed. The cDNA fragment of this gene may be generated by polymerase chain reaction (PCR) of the cDNA clone using appropriate oligonucleotide primers. Cloning sites (NcoI or SmaI) can be incorporated into the oligonucleotides to provide proper orientation of the DNA fragment when inserted into the digested vector pML103 as described below. Amplification is then performed in a standard PCR. The amplified DNA is then digested with restriction enzymes NcoI and SmaI and fractionated on an agarose gel. The appropriate band can be isolated from the gel and combined with a 4.9 kb NcoI-SmaI fragment of the plasmid pML103. Plasmid pML103 has been deposited under the terms of the Budapest Treaty at ATCC (American Type Culture Collection, 10801 University Blvd., Manassas, VA 20110-2209), and bears accession number ATCC 97366. The DNA segment from pML103 contains a 1.05 kb SalI-NcoI promoter fragment of the maize 27 kD zein gene and a 0.96 kb SmaI-SalI fragment from the 3' end of the maize 10 kD zein gene in the vector pGem9Zf(+) (Promega). Vector and insert DNA can be ligated at 15°C overnight, essentially as described (Maniatis). The ligated DNA may then be used to transform *E. coli* XL1-Blue (Epicurian Coli XL-1 Blue™; Stratagene). Bacterial transformants can be screened by restriction enzyme digestion of plasmid DNA and limited nucleotide sequence analysis using the dideoxy chain termination method (Sequenase™ DNA Sequencing Kit; U.S. Biochemical). The resulting plasmid construct would comprise a chimeric gene encoding, in the 5' to 3' direction, the maize 27 kD zein promoter, a cDNA fragment encoding the instant polypeptide, and the 10 kD zein 3' region.

The chimeric gene described above can then be introduced into corn cells by the following procedure. Immature corn embryos can be dissected from developing caryopses derived from crosses of the inbred corn lines H99 and LH132. The embryos are isolated 10 to 11 days after pollination when they are 1.0 to 1.5 mm long. The embryos are then placed with the axis-side facing down and in contact with agarose-solidified N6 medium (Chu et al. (1975) *Sci. Sin. Peking* 18:659-668). The embryos are kept in the dark at 27°C. Friable

embryogenic callus consisting of undifferentiated masses of cells with somatic proembryoids and embryoids borne on suspensor structures proliferates from the scutellum of these immature embryos. The embryogenic callus isolated from the primary explant can be cultured on N6 medium and sub-cultured on this medium every 2 to 3 weeks.

5 The plasmid, p35S/Ac (obtained from Dr. Peter Eckes, Hoechst Ag, Frankfurt, Germany) may be used in transformation experiments in order to provide for a selectable marker. This plasmid contains the *Pat* gene (see European Patent Publication 0 242 236) which encodes phosphinothricin acetyl transferase (PAT). The enzyme PAT confers resistance to herbicidal glutamine synthetase inhibitors such as phosphinothricin. The *pat* gene in p35S/Ac is under the control of the 35S promoter from Cauliflower Mosaic Virus (Odell et al. (1985) *Nature* 313:810-812) and the 3' region of the nopaline synthase gene from the T-DNA of the Ti plasmid of *Agrobacterium tumefaciens*.

10 The particle bombardment method (Klein et al. (1987) *Nature* 327:70-73) may be used to transfer genes to the callus culture cells. According to this method, gold particles (1 μm in diameter) are coated with DNA using the following technique. Ten μg of plasmid DNAs are added to 50 μL of a suspension of gold particles (60 mg per mL). Calcium chloride (50 μL of a 2.5 M solution) and spermidine free base (20 μL of a 1.0 M solution) are added to the particles. The suspension is vortexed during the addition of these solutions. After 10 minutes, the tubes are briefly centrifuged (5 sec at 15,000 rpm) and the supernatant removed. The particles are resuspended in 200 μL of absolute ethanol, centrifuged again and the supernatant removed. The ethanol rinse is performed again and the particles resuspended in a final volume of 30 μL of ethanol. An aliquot (5 μL) of the DNA-coated gold particles can be placed in the center of a Kapton™ flying disc (Bio-Rad Labs). The particles are then accelerated into the corn tissue with a Biolistic™ PDS-1000/He (Bio-Rad Instruments, Hercules CA), using a helium pressure of 1000 psi, a gap distance of 0.5 cm and a flying distance of 1.0 cm.

20 For bombardment, the embryogenic tissue is placed on filter paper over agarose-solidified N6 medium. The tissue is arranged as a thin lawn and covered a circular area of about 5 cm in diameter. The petri dish containing the tissue can be placed in the chamber of the PDS-1000/He approximately 8 cm from the stopping screen. The air in the chamber is then evacuated to a vacuum of 28 inches of Hg. The macrocarrier is accelerated with a helium shock wave using a rupture membrane that bursts when the He pressure in the shock tube reaches 1000 psi.

35 Seven days after bombardment the tissue can be transferred to N6 medium that contains bialaphos (5 mg per liter) and lacks casein or proline. The tissue continues to grow slowly on this medium. After an additional 2 weeks the tissue can be transferred to fresh N6 medium containing bialaphos. After 6 weeks, areas of about 1 cm in diameter of actively growing callus can be identified on some of the plates containing the bialaphos-

supplemented medium. These calli may continue to grow when sub-cultured on the selective medium.

Plants can be regenerated from the transgenic callus by first transferring clusters of tissue to N6 medium supplemented with 0.2 mg per liter of 2,4-D. After two weeks the tissue can be transferred to regeneration medium (Fromm et al. (1990) *Bio/Technology* 8:833-839).

EXAMPLE 7

Transformation and Regeneration of Maize Embryos

Immature maize embryos from greenhouse donor plants are bombarded with a plasmid containing the gene of the invention operably linked to a promoter; this could be a weak promoter such as nos, an inducible promoter such as In2, or a strong promoter such as Ubiquitin plus a plasmid containing the selectable marker gene PAT (Wohlleben *et al.*, 1988, *Gene* 70:25-37) that confers resistance to the herbicide Bialaphos. Transformation is performed as follows.

Maize ears are harvested 8-14 days after pollination and surface sterilized in 30% Chlorox bleach plus 0.5% Micro detergent for 20 minutes, and rinsed two times with sterile water. The immature embryos are excised and placed embryo axis side down (scutellum side up), 25 embryos per plate. These are cultured on 560 L medium 4 days prior to bombardment in the dark. Medium 560 L is an N6-based medium containing Eriksson's vitamins, thiamine, sucrose, 2,4-D, and silver nitrate. The day of bombardment, the embryos are transferred to 560 Y medium for 4 hours and are arranged within the 2.5-cm target zone. Medium 560Y is a high osmoticum medium (560L with high sucrose concentration).

A plasmid vector comprising the gene of the invention operably linked to the selected promoter is constructed. This plasmid DNA plus plasmid DNA containing a PAT selectable marker is precipitated onto 1.1 μm (average diameter) tungsten pellets using a CaCl_2 precipitation procedure as follows: 100 μl prepared tungsten particles in water, 10 μl (1 μg) DNA in TrisEDTA buffer (1 μg total), 100 μl 2.5 M CaCl_2 , 10 μl 0.1 M spermidine.

Each reagent is added sequentially to the tungsten particle suspension, while maintained on the multitube vortexer. The final mixture is sonicated briefly and allowed to incubate under constant vortexing for 10 minutes. After the precipitation period, the tubes are centrifuged briefly, liquid removed, washed with 500 μl 100% ethanol, and centrifuged for 30 seconds. Again the liquid is removed, and 105 μl 100% ethanol is added to the final tungsten particle pellet. For particle gun bombardment, the tungsten/DNA particles are briefly sonicated and 10 μl spotted onto the center of each macrocarrier and allowed to dry about 2 minutes before bombardment.

The sample plates are positioned 2 levels below the stooping plate for bombardment in a DuPont Helium Particle Gun. All samples receive a single shot at 650 PSI, with a total of ten aliquots taken from each tube of prepared particles/DNA. As a control, embryos are

bombarded with DNA containing the PAT selectable marker as described above without the gene of invention.

Following bombardment, the embryos are kept on 560Y medium, an N6 based medium, for 2 days, then transferred to 560R selection medium, an N6 based medium containing 3 mg/liter Bialaphos, and subcultured every 2 weeks. After approximately 10 weeks of selection, selection-resistant callus clones are sampled for PCR and activity of the gene of interest. In treatments containing the WUS gene, growth is stimulated and transformation frequencies increase, relative to the control. Positive lines are transferred to 288J medium, an MS based medium with lower sucrose and hormone levels, to initiate plant regeneration. Following somatic embryo maturation (2-4 weeks), well-developed somatic embryos are transferred to medium for germination and transferred to the lighted culture room. Approximately 7-10 days later, developing plantlets are transferred to medium in tubes for 7-10 days until plantlets are well established. Plants are then transferred to inserts in flats (equivalent to 2.5" pot) containing potting soil and grown for 1 week in a growth chamber, subsequently grown an additional 1-2 weeks in the greenhouse, then transferred to Classic 600 pots (1.6 gallon) and grown to maturity. Plants are monitored for expression of the gene of interest.

EXAMPLE 8

Ectopic Expression of Maize WUS to Induce Organogenesis

Using the genotype High type II as an example, embryos are isolated and cultured on 560P medium for 3-5 days. Twelve hours before bombardment these embryos are transferred to high osmotic 560Y medium. Expression cassettes containing the WUS cDNA are then co-introduced into the scutella of these embryos along with an expression cassette containing the Bar or Pat gene using methods well described in the art for particle gun transformations. Twelve to 24 hours following bombardment embryos are then transferred back to 560P culture medium and incubated in the dark at 26°C. After one week of culture these embryos are moved to 560R selection medium. Cultures are then transferred every two weeks until transformed colonies appear. Expression of WUS will stimulate adventive meristem (shoot) formation. This will be apparent when the cultures are compared to controls (transformed without the WUS cDNA or non-induced). Using either inducible expression cassettes, tissue specific promoters, or promoters of varying strengths it will be possible to control the levels of expression to maximize the formation of adventive meristems. Using either non-responsive genotypes or sub-optimal culture conditions with responsive genotypes, only the transformed cells expressing the WUS c-DNA will form meristems and regenerate plants. For experiments in which WUS-induced shoot proliferation occurs via ectopic meristem formation, WUS can be used as a positive selective phenotype and no selection agent is required in the media. In this manner the WUS gene can be used as a positive selective marker (only the cells expressing the c-DNA will form shoot

meristems) and transformants can be recovered without a negative selective agent (i.e. bialaphos, basta, kanamycin, etc.).

EXAMPLE 9

Transient Expression of the WUS Gene Product to Induce shoot Organogenesis.

5 It may be desirable to "kick start" meristem formation by transiently expressing the WUS genes product. This can be done by delivering WUS 5' capped polyadenylated RNA, expression cassettes containing WUS DNA, or WUS protein. All of these molecules can be delivered using a biolistics particle gun. For example 5' capped polyadenylated WUS RNA can easily be made *in vitro* using Ambion's mMessage mMachine kit. Following the
10 procedure outlined above, RNA is co-delivered along with DNA containing an agronomically useful expression cassette. The cells receiving the RNA will immediately form shoot meristems and a large portion of these will have integrated the agronomic gene. Plants regenerated from these embryos can then be screened for the presence of the agronomic gene.

EXAMPLE 10

Maize Meristem Transformation

Meristem transformation protocols rely on the transformation of apical initials or cells that can become apical initials following reorganization due to injury or selective pressure. The progenitors of these apical initials differentiate to form the tissues and organs
20 of the mature plant (i.e. leaves, stems, ears, tassels, etc.). The meristems of most angiosperms are layered with each layer having its own set of initials. Normally in the shoot apex these layers rarely mix. In maize the outer layer of the apical meristem, the L1, differentiates to form the epidermis while descendents of cells in the inner layer, the L2, give rise to internal plant parts including the gametes. The initials in each of these layers are
25 defined solely by position and can be replaced by adjacent cells if they are killed or compromised. Meristem transformation frequently targets a subset of the population of apical initials and the resulting plants are chimeric. If for example, 1 of 4 initials in the L1 layer of the meristem are transformed only ¼ of epidermis would be transformed. Selective pressure can be used to enlarge sectors but this selection must be non-lethal since large
30 groups of cells are required for meristem function and survival. Transformation of a meristem cell with a WUS sequence under the expression of a promoter active in the apical meristem (either meristem-specific or constitutive) would allow the transformed cells to re-direct the initiation of new apical initials driving the meristem towards homogeneity and minimizing the chimeric nature of the plant body. To demonstrate this, the WUS sequence
35 is cloned into a cassette with a promoter that is active within the meristem (i.e. either a strong constitutive maize promoter such as the ubiquitin promoter including the first ubiquitin intron, or a promoter active in meristematic cells such as the maize histone, cdc2 or actin promoter). Coleoptilar stage embryos are isolated and plated meristem up on a high

sucrose maturation medium (see Lowe et al., 1997, In *Genetic Biotechnology and Breeding of Maize and Sorghum*, AS Tsafaris, ed., Royal Society of chemistry, Cambridge, UK, pp94-97). The WUS expression cassette along with a reporter construct such as

Ubi:GUS:pinII can then be co-delivered (preferably 24 hours after isolation) into the

5 exposed apical dome using conventional particle gun transformation protocols. As a control the WUS construct can be replaced with an equivalent amount of pUC plasmid DNA. After a week to 10 days of culture on maturation medium the embryos can be transferred to a low sucrose hormone-free germination medium. Leaves from developing plants can be sacrificed for GUS staining. Transient expression of the WUS sequence in meristem cells, 10 through formation of new apical initials, will result in broader sectors or completely transformed meristems increasing the probability of germ-line transformation. Integration and expression of the WUS sequence will impart a competitive advantage to expressing cells resulting in a progressive enlargement of the transgenic sector. Due to the WUS-induced maintenance of apical initials and growth of their transformed derivatives, they will supplant 15 wild-type meristem cells as the plant continues to grow. The result will be both enlargement of transgenic sectors within a given cell layer (i.e. periclinal expansion) and into adjacent cell layers (i.e. anticlinal invasions). As cells expressing the WUS gene occupy an increasingly large proportion of the meristem, the frequency of transgene germline inheritance goes up accordingly. Using WUS in this manner to target meristems will 20 increase transformation rates, relative to control treatments. Coleoptilar-stage embryos used as a source of meristems is used as an example, but other meristem sources could be used as well, for example immature inflorescences.

EXAMPLE 11

Expression of Chimeric Genes in Dicot Cells

25 A seed-specific expression cassette composed of the promoter and transcription terminator from the gene encoding the β subunit of the seed storage protein phaseolin from the bean *Phaseolus vulgaris* (Doyle et al. (1986) *J. Biol. Chem.* 261:9228-9238) can be used for expression of the instant polypeptides in transformed soybean. The phaseolin cassette includes about 500 nucleotides upstream (5') from the translation initiation codon and about 30 1650 nucleotides downstream (3') from the translation stop codon of phaseolin. Between the 5' and 3' regions are the unique restriction endonuclease sites Nco I (which includes the ATG translation initiation codon), Sma I, Kpn I and Xba I. The entire cassette is flanked by Hind III sites.

The cDNA fragment of this gene may be generated by polymerase chain reaction 35 (PCR) of the cDNA clone using appropriate oligonucleotide primers. Cloning sites can be incorporated into the oligonucleotides to provide proper orientation of the DNA fragment when inserted into the expression vector. Amplification is then performed as described

above, and the isolated fragment is inserted into a pUC18 vector carrying the seed expression cassette.

Soybean embryos may then be transformed with the expression vector comprising sequences encoding the instant polypeptides. To induce somatic embryos, cotyledons, 3-5 mm in length dissected from surface sterilized, immature seeds of the soybean cultivar A2872, can be cultured in the light or dark at 26°C on an appropriate agar medium for 6-10 weeks. Somatic embryos which produce secondary embryos are then excised and placed into a suitable liquid medium. After repeated selection for clusters of somatic embryos which multiplied as early, globular staged embryos, the suspensions are maintained as described below.

Soybean embryogenic suspension cultures can be maintained in 35 mL liquid media on a rotary shaker, 150 rpm, at 26°C with florescent lights on a 16:8 hour day/night schedule. Cultures are subcultured every two weeks by inoculating approximately 35 mg of tissue into 35 mL of liquid medium.

Soybean embryogenic suspension cultures may then be transformed by the method of particle gun bombardment (Klein et al. (1987) *Nature* (London) 327:70-73, U.S. Patent No. 4,945,050). A DuPont Biolistic™ PDS1000/HE instrument (helium retrofit) can be used for these transformations.

A selectable marker gene which can be used to facilitate soybean transformation is a chimeric gene composed of the 35S promoter from Cauliflower Mosaic Virus (Odell et al. (1985) *Nature* 313:810-812), the hygromycin phosphotransferase gene from plasmid pJR225 (from *E. coli*; Gritz et al. (1983) *Gene* 25:179-188) and the 3' region of the nopaline synthase gene from the T-DNA of the Ti plasmid of *Agrobacterium tumefaciens*. The seed expression cassette comprising the phaseolin 5' region, the fragment encoding the instant polypeptide and the phaseolin 3' region can be isolated as a restriction fragment. This fragment can then be inserted into a unique restriction site of the vector carrying the marker gene.

To 50 µL of a 60 mg/mL 1 µm gold particle suspension is added (in order): 5 µL DNA (1 µg/µL), 20 µL spermidine (0.1 M), and 50 µL CaCl₂ (2.5 M). The particle preparation is then agitated for three minutes, spun in a microfuge for 10 seconds and the supernatant removed. The DNA-coated particles are then washed once in 400 µL 70% ethanol and resuspended in 40 µL of anhydrous ethanol. The DNA/particle suspension can be sonicated three times for one second each. Five µL of the DNA-coated gold particles are then loaded on each macro carrier disk.

Approximately 300-400 mg of a two-week-old suspension culture is placed in an empty 60x15 mm petri dish and the residual liquid removed from the tissue with a pipette. For each transformation experiment, approximately 5-10 plates of tissue are normally bombarded. Membrane rupture pressure is set at 1100 psi and the chamber is evacuated to a vacuum of 28 inches mercury. The tissue is placed approximately 3.5 inches away from the

retaining screen and bombarded three times. Following bombardment, the tissue can be divided in half and placed back into liquid and cultured as described above.

Five to seven days post bombardment, the liquid media may be exchanged with fresh media, and eleven to twelve days post bombardment with fresh media containing 50 mg/mL hygromycin. This selective media can be refreshed weekly. Seven to eight weeks post bombardment, green, transformed tissue may be observed growing from untransformed, necrotic embryogenic clusters. Isolated green tissue is removed and inoculated into individual flasks to generate new, clonally propagated, transformed embryogenic suspension cultures. Each new line may be treated as an independent transformation event. These suspensions can then be subcultured and maintained as clusters of immature embryos or regenerated into whole plants by maturation and germination of individual somatic embryos.

EXAMPLE 12

Expression of Chimeric Genes in Microbial Cells

The cDNAs encoding the instant polypeptides can be inserted into the T7 *E. coli* expression vector pBT430. This vector is a derivative of pET-3a (Rosenberg et al. (1987) *Gene* 56:125-135) which employs the bacteriophage T7 RNA polymerase/T7 promoter system. Plasmid pBT430 was constructed by first destroying the EcoR I and Hind III sites in pET-3a at their original positions. An oligonucleotide adaptor containing EcoR I and Hind III sites was inserted at the BamH I site of pET-3a. This created pET-3aM with additional unique cloning sites for insertion of genes into the expression vector. Then, the Nde I site at the position of translation initiation was converted to an Nco I site using oligonucleotide-directed mutagenesis. The DNA sequence of pET-3aM in this region, 5'-CATATGG, was converted to 5'-CCCATGG in pBT430.

Plasmid DNA containing a cDNA may be appropriately digested to release a nucleic acid fragment encoding the protein. This fragment may then be purified on a 1% low melting agarose gel. Buffer and agarose contain 10 µg/ml ethidium bromide for visualization of the DNA fragment. The fragment can then be purified from the agarose gel by digestion with GELase™ (Epicentre Technologies, Madison, WI) according to the manufacturer's instructions, ethanol precipitated, dried and resuspended in 20 µL of water. Appropriate oligonucleotide adapters may be ligated to the fragment using T4 DNA ligase (New England Biolabs (NEB), Beverly, MA). The fragment containing the ligated adapters can be purified from the excess adapters using low melting agarose as described above. The vector pBT430 is digested, dephosphorylated with alkaline phosphatase (NEB) and deproteinized with phenol/chloroform as described above. The prepared vector pBT430 and fragment can then be ligated at 16°C for 15 hours followed by transformation into DH5 electrocompetent cells (GIBCO BRL). Transformants can be selected on agar plates containing LB media and 100 µg/mL ampicillin. Transformants containing the gene

encoding the instant polypeptide are then screened for the correct orientation with respect to the T7 promoter by restriction enzyme analysis.

For high level expression, a plasmid clone with the cDNA insert in the correct orientation relative to the T7 promoter can be transformed into *E. coli* strain BL21(DE3) (Studier et al. (1986) *J. Mol. Biol.* 189:113-130). Cultures are grown in LB medium containing ampicillin (100 mg/L) at 25°C. At an optical density at 600 nm of approximately 1, IPTG (isopropylthio- β -galactoside, the inducer) can be added to a final concentration of 0.4 mM and incubation can be continued for 3 h at 25°. Cells are then harvested by centrifugation and re-suspended in 50 μ L of 50 mM Tris-HCl at pH 8.0 containing 0.1 mM DTT and 0.2 mM phenyl methylsulfonyl fluoride. A small amount of 1 mm glass beads can be added and the mixture sonicated 3 times for about 5 seconds each time with a microprobe sonicator. The mixture is centrifuged and the protein concentration of the supernatant determined. One μ g of protein from the soluble fraction of the culture can be separated by SDS-polyacrylamide gel electrophoresis. Gels can be observed for protein bands migrating at the expected molecular weight.

EXAMPLE 13

Use of Flp/Frt system to excise the WUS cassette

In cases where the WUS gene has been integrated and WUS expression is useful in the recovery of maize transgenics (i.e. under conditions where continuous expression of WUS promotes adventive meristem formation), but is ultimately not desired in the final product, the WUS expression cassette (or any portion thereof that is flanked by appropriate FRT recombination sequences) can be excised using FLP-mediated recombination (see US Patent Application 08/972,258 filed November 18, 1997).

The above examples are provided to illustrate the invention but not to limit its scope. Other variants of the invention will be readily apparent to one of ordinary skill in the art and are encompassed by the appended claims. All publications, patents, and patent applications cited herein are hereby incorporated by reference.